GEOLOGICAL APPRAISAL OF THE KISH, BURFORD, BRAY AND FRASER BANKS, OUTER DUBLIN BAY AREA

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ABSTRACT

Geological mapping of the seabed and sub-seabed strata in an area comprising offshore banks and intervening sediments in outer Dublin Bay is presented. Bathymetric comparisons suggest that the offshore banks are quasi-stable over time probably maintaining their position due to the interaction between wave and current regimes. Seven acoustic seabed facies are defined on the basis of side-scan sonar characteristics reflecting differences in bedforms and bottom types. Sediment waves indicative of a mobile substrate are common both on and between banks. Maximum sandwave development occurs on bank flanks and outer limits. The effects of wave action on seabed morphology are clearly discernible in the structure and appearance of the bank crests. Grain-size data and bedform interpretations suggest a northerly sediment transport system with gravel dominant in the south of the area (Bray Bank) grading to sands in the north (Kish and Burford Banks). Sub-bottom profiling reveals a consistent upper unit overlying a hard reflector allowing unit thickness (isopachs) to be defined. No internal structures or "hard" cores were revealed within banks. Two shipwrecks were also imaged.

This report forms part of a larger project "Reconnaissance Assessment of Coastal Seabed Sand and Gravel Resources" whose objective is to provide a comprehensive national survey, for the island of Ireland, of near-shore sand and gravel resources, to a water-depth of 50m, pertinent to all end-users *e.g.* aggregates industry, fisheries, local authorities, etc.

The aims of this larger project are to:
1. collate all known information (digital, documentary, archival and other sources) regarding the location and extent of the resources;
2. deliver this data as a national resource inventory using a GIS database in line with national standards;
3. ground-truth and extend the existing data coverage through additional surveys, where perceived data gaps or data ambiguities exist pertinent to national needs.

The resulting database (items 1 and 2) is comprised of three elements:

- A MS Access database hosting comprehensive records of 63 datasets. Accessible from the metadata record for each dataset are:
- An archive of digital thematic data in ArcView shapefile format with associated legends, tables, and imagery;
- A bibliographic database containing 406 bibliographic entries.

This report addresses Aim 3 of the larger project (above): "ground-truth and extend the existing data coverage through additional surveys, where perceived data gaps or data ambiguities exist pertinent to national needs".

Geological Appraisal of the Kish, Burford, Bray and Fraser Banks, Outer Dublin Bay Area

1. Rationale

This survey was designed to fill a perceived gap in baseline geological data pertinent to an appraisal of Irish offshore sand and gravel resources. In this respect, the survey was specifically designed to acquire fundamental data to be placed in the public-domain for an area where extraction could potentially occur and data were scant. It is also recognised that this survey may be of future use to other marine resource users and managers. This survey does not constitute part of an EIA for potential aggregate extraction or other purposes.

The designated survey area, encompassing a number of offshore banks and intervening seabed exists close to Dublin, the unprecedented expansion of which presents a potentially large market for marine aggregates. The area is mapped in three dimensions with side-scan sonar and seismic data. Ground truthing is based on surface sediment samples. Partly due to operational difficulties in surveying offshore banks, the bulk of the area has not been previously evaluated.

2. Regional Context and Existing Data

The southern Irish Sea is characterised by a series of NNE-SSW trending bedforms and sedimentary facies reflecting the principal tidal current direction. In the western Irish Sea, on the south-eastern seaboard of Ireland, at a distance of approximately 10km offshore, a series of coast-parallel north-south trending offshore-banks exist. These banks stand in 20-30m of water and rise to within a few metres of the water surface. The banks form a punctuated line along the eastern Irish coast south of Dublin with breaks maintained by strong current and sediment movements. They offer wave protection to the coast and have a strong control on tidal flow pathways along the coast. The banks are quasi-stable features in dynamic equilibrium with tidal and wave conditions and are an integral part of the coastal system resulting from coastal erosion and the remobilisation of land-based gravel deposits in north Co. Wicklow (Warren & Keary, 1989).

The largest of the banks in the survey area are the Kish Bank and Bray Bank, the Bray Bank being a southerly continuation of the former (Figure 2.1). The Kish Lighthouse marks the northern end of the Kish Bank and the Codling Bank (a shallow platform of scoured seabed) marks the southern end of the Bray Bank. The Burford Bank is *c.* 5km landward of the Kish Lighthouse and sits centrally across the mouth of Dublin Bay that forms a semi-circular embayment 8km across bordered by rocky coastline to the north (Howth) and south (Dun Laoghaire and Dalkey). South of Dalkey exists the smaller Fraser Bank which is only *c.* 2km offshore, immediately south of Muglins.

Limited public-domain data exists for the survey area although extensive datasets exist for adjacent areas with occasional survey lines impinging upon, and samples taken within, the limits of the survey area. Relevant geological survey cruise data from areas adjacent to the survey area include the R.V. Lough Beltra Regional

Mapping Cruises 10.10.76; 5.9.78; 29.10.79, and GSI cruise 2/84 and 5/84 (Geoghegan, 1986) which are held by the Geological Survey of Ireland in its GEOMAN database.

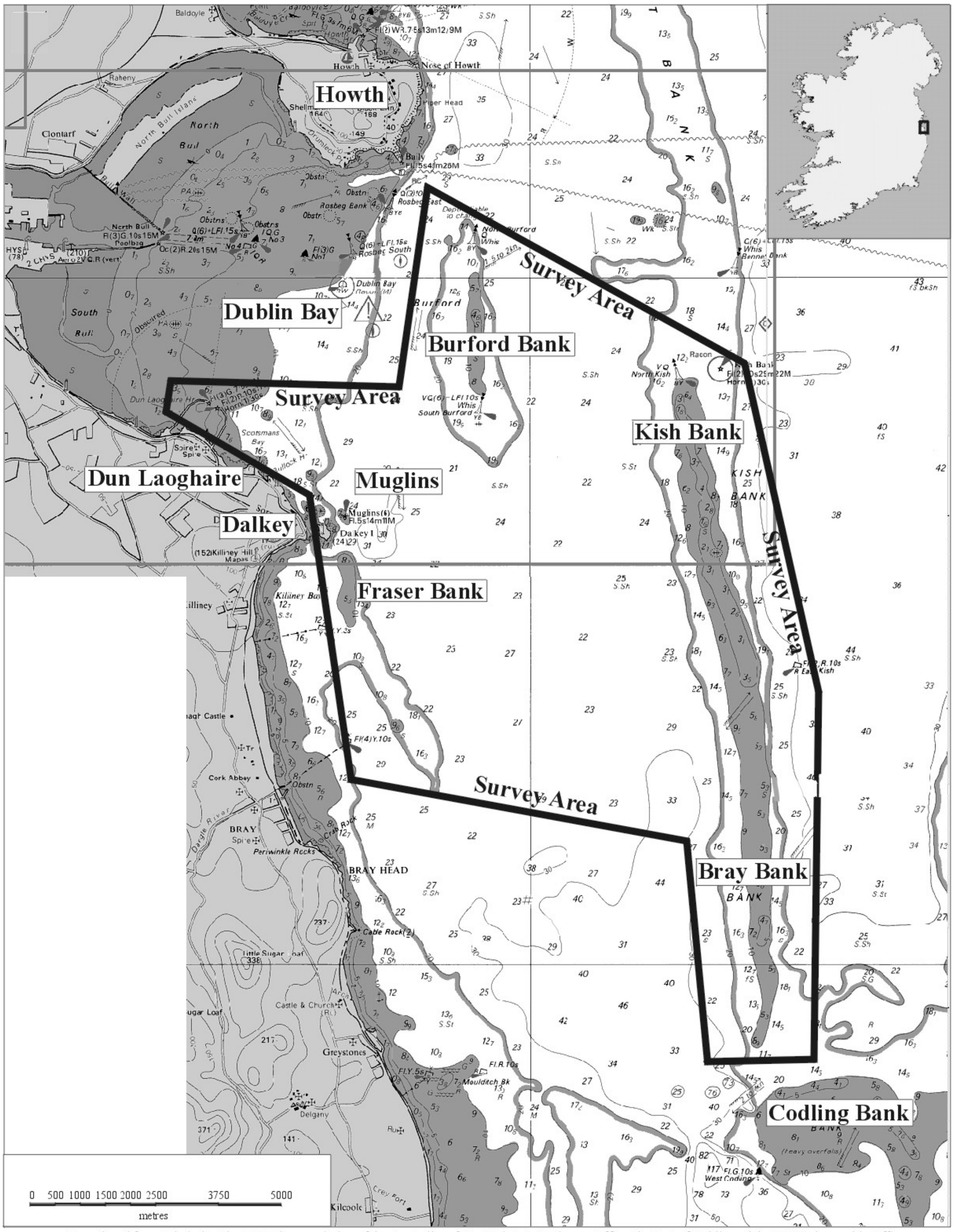

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Figure 2.1. General location map

Pertinent details of these cruises can also be visualised in a database and GIS (Sutton & Wheeler, in prep.). These cruises primarily concentrate on areas south of the survey area. Existing sample coverage (61 samples) for the area is documented in the BGS commercial samples database, the metadata of which are also presented within the sand and gravel database (Sutton & Wheeler, in prep.). Of these samples, 36% are diver samples concentrated on the Kish Bank and towards the Burford Bank, 8% are dredge samples from the Kish and Bray Bank, 8% are shipek samples between the Banks and 48% are of an unknown type. Some of this data is also discussed in Harris (1980).

The regional seabed sediment map (British Geological Survey & Geological Survey of Ireland, 1990) includes coverage of the survey area and is compiled from a number of sources. Sample sites (dredge, grab and diver samples) are marked on the map with details held by the Geological Survey of Ireland in its GEOMAN database. The map depicts the survey area as covered by "sand" with a tongue of "slightly gravelly sand" extending up the western side of the Kish Bank. West of the Bray Bank, this facies forms a continuous coverage towards the coast with sediments in a deep scour adjacent to the bank characterised by "gravelly sand" and "sandy gravel". This deep scour was formed due to Weichselian ice margin processes (Wingfield, 1990) or, more specifically, by glacial melt-water channel activity (Warren & Keary, 1989). A small area of gravelly sand is also identified southeast of the Fraser Bank.

A regional Quaternary stratigraphy for the area is presented in Whittington (1977) based on nearshore survey data south of Dublin. He identifies the four seismostratigraphic units:

Unit IV – banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows.
Unit III - horizontal or "draping" events, depositional in origin with no recognised erosional phases (due to the nature of deposition may include "softer" soils).
Unit II - glacial till, few internal reflectors, with point source diffractors suggesting boulders.
Unit I - pre-Pleistocene bedrock.

A detailed study has been performed south of the area which confirms and adds detail to the above seismostratigraphy (McKenna, 1984).

A detailed site survey exists in a $2km^2$ area immediately north-east of the survey area (Irish Shell Petroleum Development Company, 1979) based on echo-sounder, side-scan sonar and seismic sparker data. This study was performed for hydrocarbon exploration purposes in the Kish Bank Basin where coal reserves have also been found (Jenner, 1981; McArdle & Keary, 1986; Geoghegan *et al.*, 1989). The report identifies a consistent reflector (reflector A) within Whittington's Unit IV. This is correlated with "stiff clay" at 15 to 16m in a borehole at the Kish Lighthouse. This borehole documents 15m of "fine sand" overlying the "stiff clay" unit and more than 11m of "dark grey cohesive silt with some sand" underlying the "stiff clay" unit. Irish Shell Petroleum Development Company (1979) extrapolate this unit to a minimum depth of 45m (the base of Whittington's Unit IV). Side-scan sonar and bathymetric data identified asymmetrical sandwaves, 1 to 1.5m high with a wavelength of about 600m trending east-west with lee slopes facing northwards (Irish Shell Petroleum Development Company, 1979). The recorded wavelength of 600m is questioned here and suggested that a wavelength of 60m may have been intended. Rippled fine sands with gravel patches in their troughs are documented. The ripples are again asymmetrical being 0.8m high with a wavelength of 10m (Irish Shell Petroleum Development Company, 1979). The wavelength or definition of ripples is also questioned here and suggested that the reference to ripples relates to smaller scale sandwaves. Gravel patches covering $20m^2$ were also imaged. Measurements of current strengths suggest that for at least 8–hours over spring tides, current velocities exceed the $^1/_3$ to ½ knot speed (0.17 to $0.25ms^{-1}$) necessary to transport these fine to medium sands.

Repeat biological and geological surveys of Dublin Bay, west of the study area, have been performed mainly for assessing the fate and impact of dredge and sewage spoil (*e.g.* Naylor 1965; Max *et al*., 1976; Harris, 1980; Keegan, *et al*., 1983; Wilson, 1984; Keegan, 1989). These studies document the presence of rippled fine sand covering most of the bay. A dredge spoil site exists *c.*5 km due west of the Burford Bank.

One of the highest concentration of shipwrecks found in Irish waters exists on the banks in the survey area. This density reflects both the navigational hazard associated with these natural barriers and the scale of Dublin port traffic. A National Maritime Sites and Monuments Record is held by Duchas - The Heritage Service that lists the site of all known shipwrecks in the area, many of which are also listed in Bourke (1994, 1999).

3. Materials & Methods

A preliminary assessment of the coastal sand and gravel database (Sutton & Wheeler, in prep.) was performed to assess geographical areas where the presence of significant sand and gravel deposits was considered likely although fundamental survey data were sparce. Several areas were prioritised and a steering committee composed of representations from project partners (Irish Hydrodata Ltd., Geological Survey of Ireland, Bilberry Shipping & Stevedores Ltd.) and the Marine Institute made a judicious decision to determine a priority survey area. The selection process was conducted following consultation at a public workshop (Marine Research Measures Irish Offshore Sand & Gravel Workshop, University College Cork, June 12th, 1998). This decision also took into account the likelihood that aggregate extraction or other developments might be proposed for this area, the perceived value of the resource, and the availability of a market for the resource.

The vessel used for this survey was the M.V. Kilquade, a steel-hulled Clovelly class Ex. R.M.A.S. fleet-tender. She is 24.08m long, with a draft of 2.44m and beam of 6.70m, capable of a top speed of 10 knots. Positioning was accomplished by means of a Trimble NT300D DGPS with 1-2m accuracy. Navigation data was logged (with bathymetric signal) through Hypack software to a computer hard-disk.

The survey used side-scan sonar to map the seabed, elucidating bedforms that are suggestive of sediment mobility, inferring sediment type based on truthed acoustic facies and locating shipwrecks. A Geoacoustics dual frequency (100kHz and 410kHz) side-scan sonar system was used with the 100kHz frequency employed and the signal sent to an Ultra Electronics Wideline 200 Series thermographic recorder. The side-scan sonar operated well although there was some channel fall-out in high currents when run parallel to the bank due to angling of the tow-fish.

Boomer seismic coverage was generated and recorded concurrently (metocean conditions permitting) to provide stratigraphic data and generate isopachs (contours of equal sediment thickness) for the upper sand and gravel facies. A boomer plate mounted on a catamaran was powered by an Applied Acoustic Engineering CSP 1000 capacitor discharge power supply. Return signals were detected with an EG&G Model 262-J hydrophone and processed with an Octopus Marine Systems 360 Sub-bottom processor system. Hardcopy recording was made on an Ultra Electronics Wideline 200 Series thermographic recorder. The system failed to operate under relatively high wave regimes due to air-trapping under the boomer plate and also connection failures caused by excessive strain. In calmer conditions, the boomer performed well. The optimum configuration of towed acoustic gear is presented in Figure 3.1. The side-scan sonar towfish was moved closer to the vessel when operating over the banks.

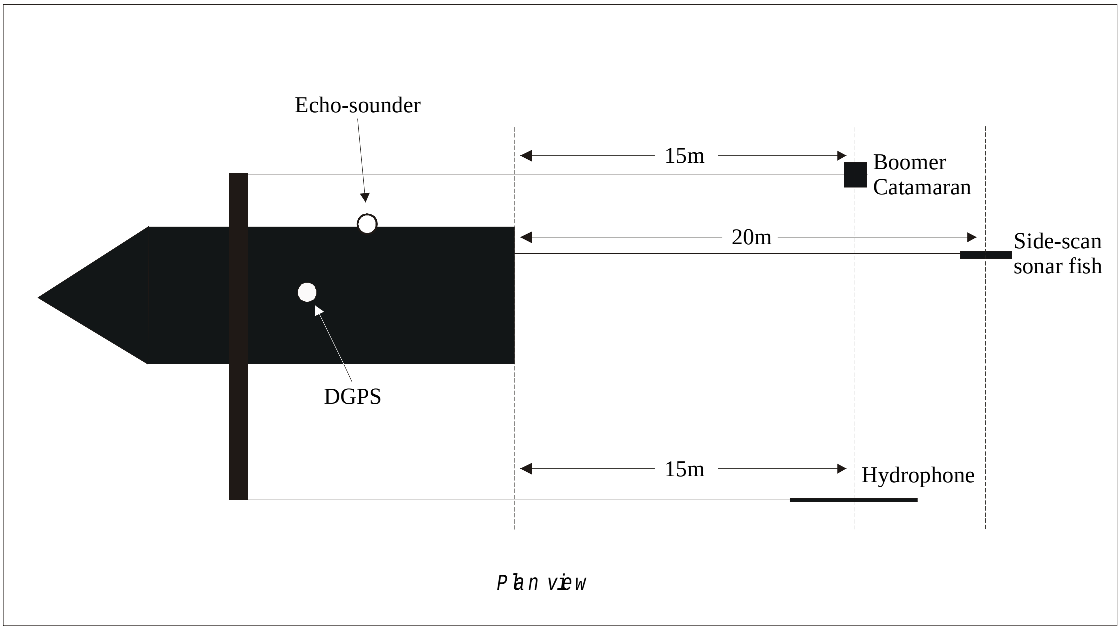

Figure 3.1. Lay-back of acoustic survey gear showing optimum survey configuration.

Bathymetric data was collected using an Odom Echotrac Model 3100 (200kHz) echo-sounder. Online survey guidance and simultaneous logging of bathymetric and positioning data were handled through a PC running the Coastal Oceanographics Hypack survey program. An Odom Digibar Model 1100 was used to measure the speed of sound in the water column to provide calibration data for the echo-sounder. The system performed well although initial problems were encountered holding the transducer in position during relatively high wave states. Tidal levels were recorded at Dun Laoghaire and Dublin Port with a time correction of –20 minutes applied for data reduction at the working site. An independent manual check on the tide gauge was performed.

A Van Essen Grab was used to collect all sediment samples. Samples collected were then subjected to particle size analysis using laser granulometry for grains less than 2mm on a Malvern Instruments Mastersizer X particle sizer (Jantschik *et al*., 1992). Grains greater than 2mm were wet sieved and the two datasets subsequently integrated. Percentage carbonate determinations were performed by loss-on-ignition (Dean, 1974) at 1000^{o}C for 2 hours.

An attempt was also made to acquire underwater video imagery along the banks to assist in the interpretation of acquired datasets and provide additional biological information. This was abandoned due to operational problems associated with the high current regime. It was also realised that the mobility of the seabed sediment during the majority of the tidal cycle would severely occlude visibility and therefore limit the usefulness of the video imagery.

Surveying was carried out during spring tides (between 3.11.98 and 10.11.98) to enable the vessel to effectively clear the banks at high tide. The survey took place with the following scientific personnel: Andy Wheeler (chief scientist), Jim Walshe (geophysicist) and Gerry Sutton (hydrographer). Weather conditions were changeable and included periods of NE gales force 6-7 swinging around to SW gales force 7-8. Moderate conditions existed which were operational between these peak events. Work on the banks was strongly dictated by the height of the tide and the relationship of the tidal flow to wind direction governing wave height.

Isobaths and isopachs were produced from gridded data using standard contouring computations.

4. Bathymetric Changes

New bathymetric data was collected during the survey and compared with existing bathymetry available on Admiralty navigation charts (Hydrographic Office, 1978). This intercomparison was performed to assess whether there was a discernible shift in bank location and altitude. The cruise track for echo-sounder data is presented in Figure 4.1. Isobaths were produced from the gridding of the acquired bathymetric data and are presented overlying the existing Admiralty isobaths (Figure 4.2). The existing Admiralty isobaths were compiled from data collected between 1843 and 1911. The intercomparison reveals a close match implying that no substantial movement has occurred on the Burford Bank. The intercomparison on the Kish Bank and Bray Bank is also good for deeper isobaths but less so in the shallower waters and on the crest. The new bathymetric data suggests the Admiralty charts reliably locate the banks although differences in crestal elevations make the charts unsuitable for across-bank navigation. These conclusions are presented with the caveat that there are inherent differences between the systems used to derive and chart positions associated with the two datasets, and an unqualified difference between the respective methods used to generate isobaths.

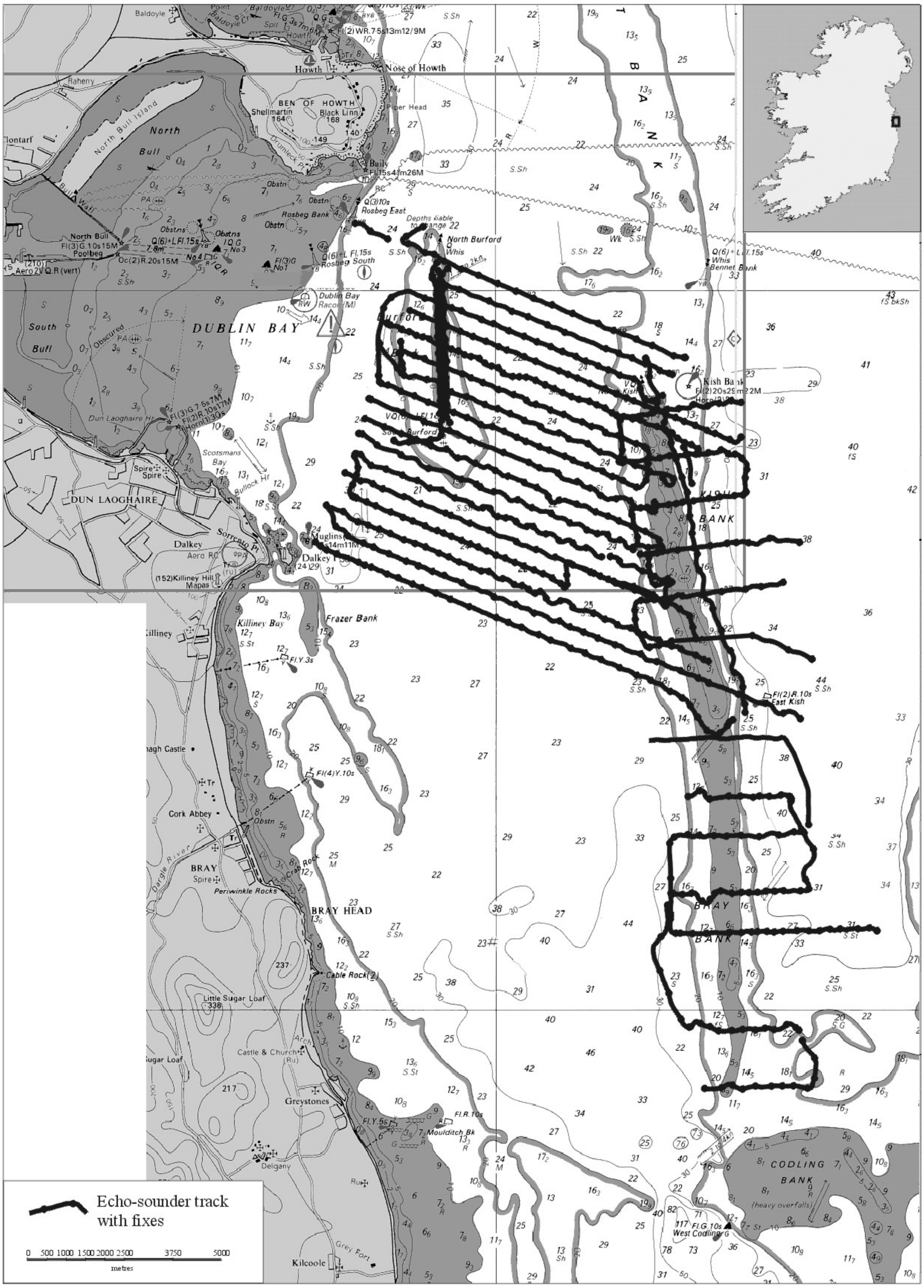

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Figure 4.1. Echo-sounder cruise track.

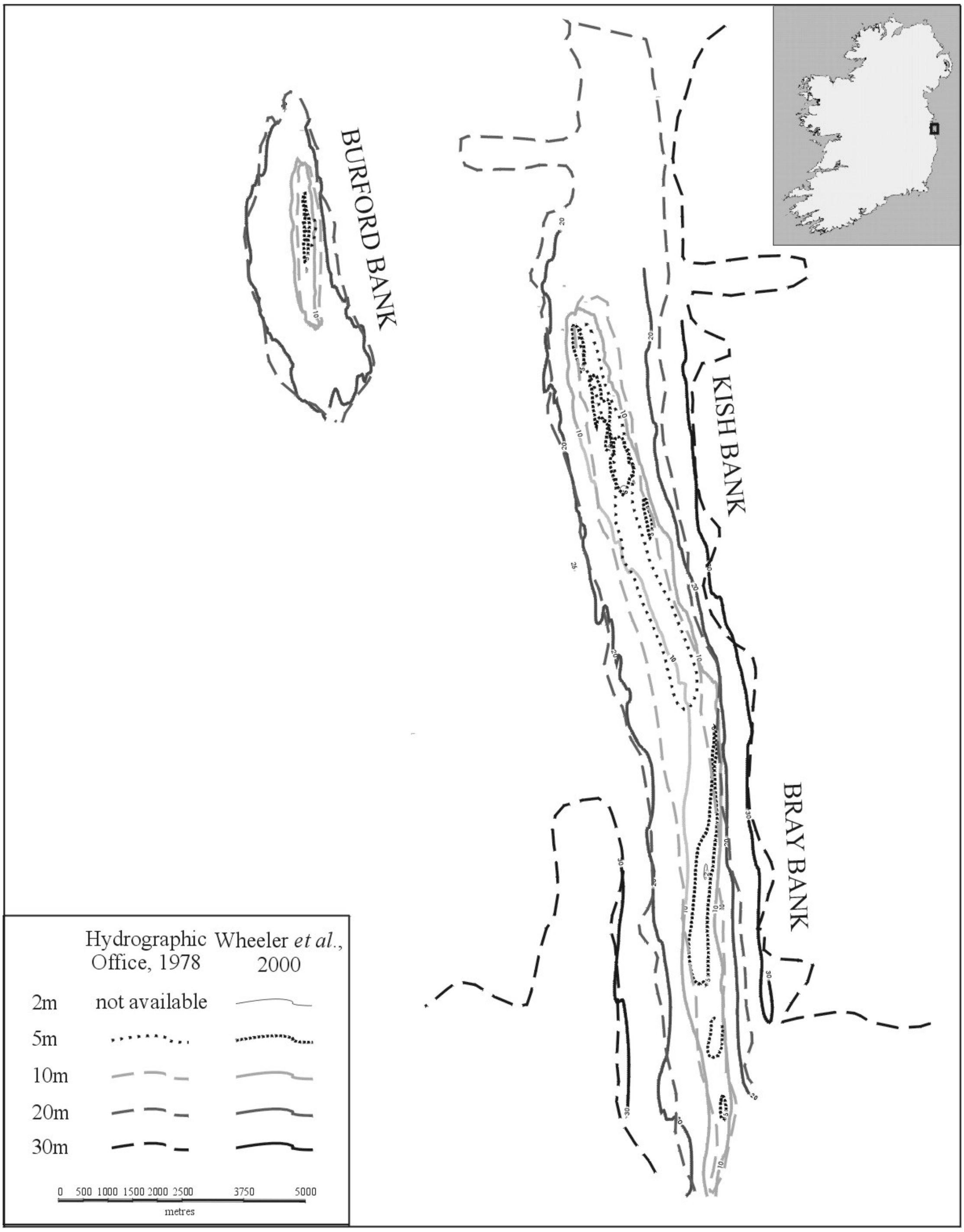

Figure 4.2. Bathymetric intercomparison.

5. Seafloor facies, bedforms and sediment mobility

Side-scan sonar was used to map the seafloor on and between the banks. This was done to assist in fundamental geological mapping as well as to elucidate the nature of geological processes through facies allocations and the interpretation of bedforms. Side-scan sonar coverage is presented in Figure 5.1 and shows a minimum 25% coverage of the total seabed within the survey area, with 75% coverage generated for most areas including the Kish Bank, Burford Bank and intervening seabed. The coverage includes across-bank and crest-parallel swathes on the Burford and Kish Banks with across-bank lines only for the Fraser and Bray Banks.

Side-scan sonographs were ascribed to facies based on a consideration of backscatter intensity and bedforms. Acoustic facies (Figure 5.2) show a predominantly north-south or bank-parallel zonation suggesting that controls on bank processes extend to contiguous areas. Several facies are defined and described below. It is appreciated that facies allocations are mildly affected by variable data quality due to changing metocean conditions during surveying. This factor may help to explain in part the limited presence of the "stippled stable seabed facies" and apparent extensions to the "stippled sandwave facies" between the Kish and Burford Banks (Figure 5.2).

5.1. Stable seabed facies

The "stable seabed facies" is found in areas between the banks and is so called because no bedforms were imaged with the side-scan sonar. The facies probably represents stable or non-mobile seabed although small scale ripples may exist that were too small to be detected by the side-scan sonar. An example of this facies (Figure 5.3a) shows a characteristic homogeneity of backscatter return. Ground-truthing implies that this featureless facies represents a flat sandy to silty seafloor.

5.2. Sandwave facies

The "sandwave facies" describes a mobile seabed that occurs on the outer limits of the bank complex and Fraser Bank. Figures 5.3b to 5.4c show representative sonographs from this facies which is characterised by lunate asymmetrical sandwaves implying northerly net sediment transport. The wavelength and amplitude of the sandwaves are variable (see a comparison between Figures 5.4a & 5.4b), with sandwave fields often forming onlapping domains (Figures 5.3b to 5.3d). This facies also exhibits clearly delimited sand ribbons surrounded by seabed with lower relief bedforms (Figure 5.3b). Small sandwaves (Figure 5.4b) are more common at the edge of the facies where it borders the "stable seabed facies". The larger sandwaves (Figure 5.4a), sand ribbons (Figure 5.3b) and mixed sandwave fields (Figure 5.3c & 5.3d) are common near the outer limits of the banks. This pattern suggests that the strongest tidal flows are found closest to the bank, probably due to acceleration in tidal flows around the obstruction. Stable bank locations are probably dependent on the dynamic interaction of wave action causing up-bank sediment migration and strong tidal boundary currents preventing further landward sediment migration. One ridge of sand (Figure 5.4c) is present between the Burford and Kish Banks representing a linear accumulation of sand where two sediment transport domains meet.

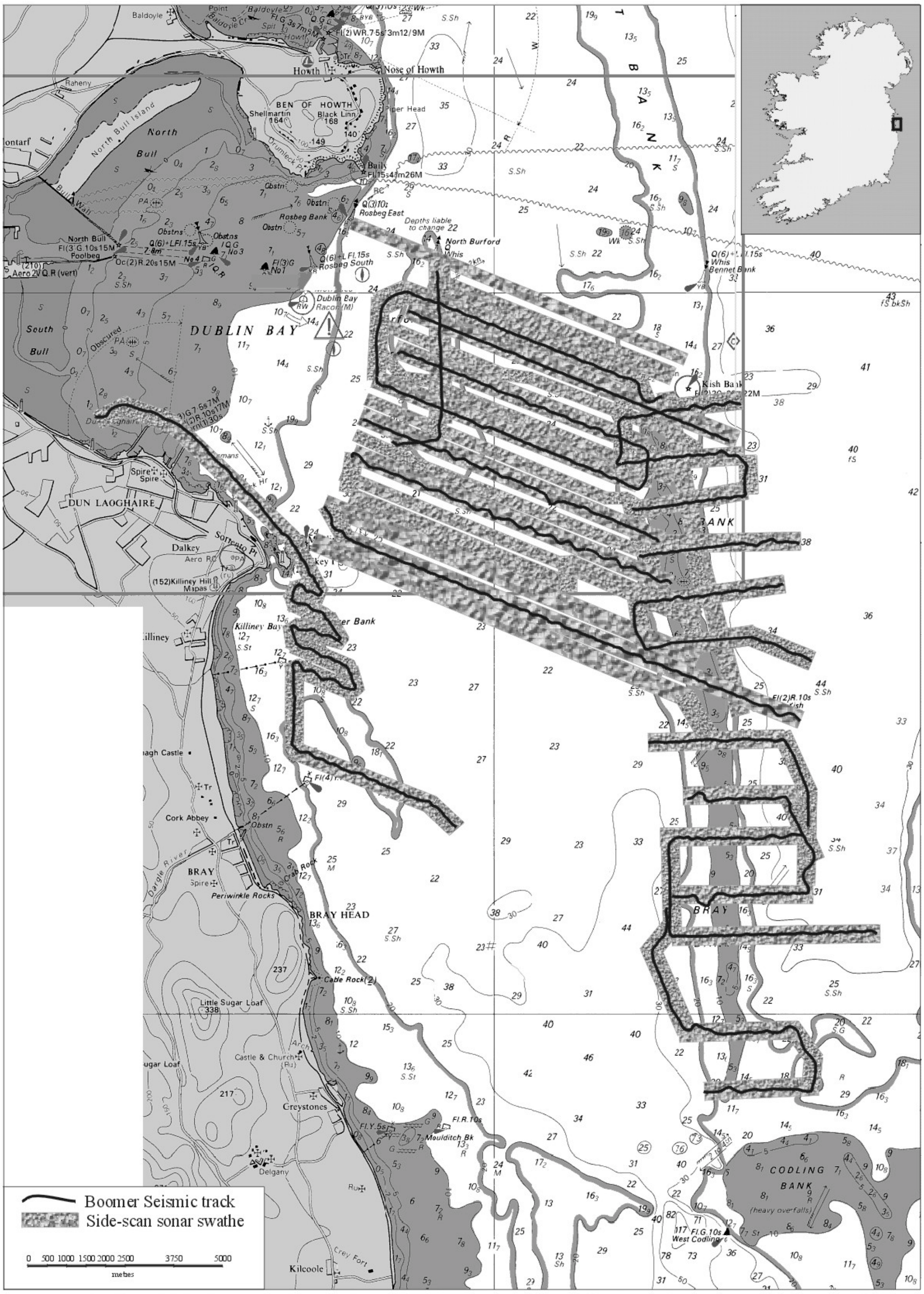

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Figure 5.1. Side-scan sonar and boomer seismic coverage.

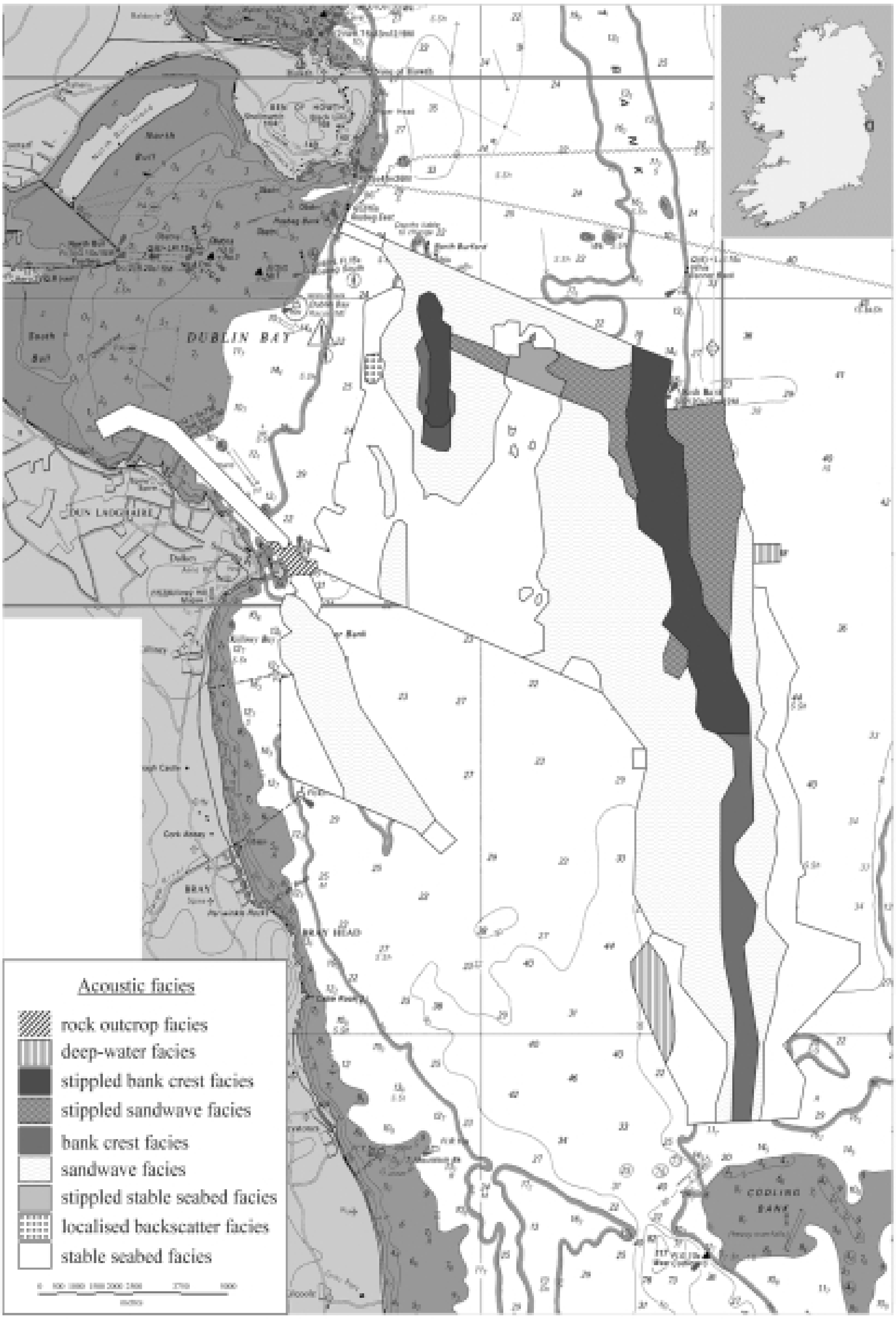

Figure 5.2. Acoustic facies based on geophysical data.

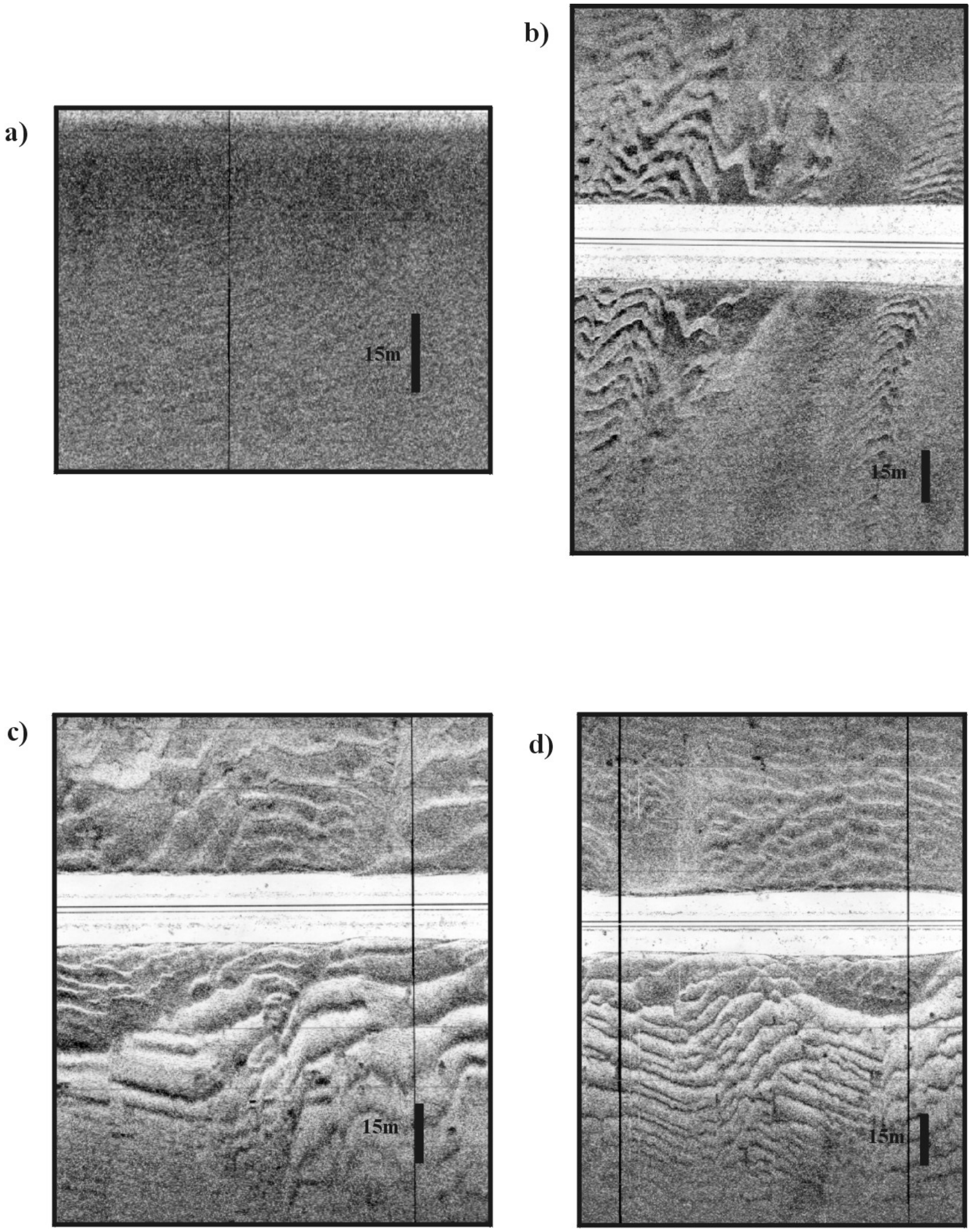

Figure 5.3. Examples of side-scan sonographs showing a) the "stable seabed facies"; b) discrete domains of sandwaves and sand ribbons in the "sandwave facies"; and c)& d) mixed fields of onlapping large sandwaves in the "sandwave facies"

5.3. Stippled bank crest facies

The “stippled bank crest facies” characterises the crest of the Kish and Burford Banks and is represented by a transition from sandwaves, on the edge of the bank, to planar beds with numerous small patches of highly reflective seabed (probable gravel patches) (Figures 5.4d, 5.5a, 5.5b and 5.5c). The patches of highly reflective material occur in discrete areas of variable size although larger patches are apparent in shallower water (Figure 5.5a). Sandwaves in this facies have sinuous crests (Figure 5.5c) implying a northerly sediment transport direction along the crest of the Banks. Where water-depths are shallowest overlying the banks, planar beds often replace sandwaves (Figure 5.5b).

5.4. Stippled sandwave facies

Patches of highly reflective material (probable gravel patches) are also present away from the banks in areas dominated by sandwaves (“stippled sandwave facies”). This facies occurs on the edges of the Kish Bank and in a narrow strip between the Kish and Burford Banks (Figure 5.2).

5.5. Stippled stable seabed facies

Patches of highly reflective material lying on the seabed that has an otherwise homogeneous backscatter define a narrow strip of “stippled stable seabed facies” (Fig. 5.2).

5.6. Bank-crest facies

The “bank-crest facies” describes the crest of the Bray Bank and the outer edges of the Burford Bank. This facies is similar to the “stippled bank crest facies” except there is an absence of highly reflective material (probable gravel patches).

5.7. Minor facies

Several other minor facies are also defined, these include the “deep-water facies” which occurs on the edge of a deep scour west of the Bray Bank. In common with the “stable seabed facies”, this facies is characterised by a uniform featureless acoustic backscatter signal although a generally higher degree of backscatter is exhibited, probably reflecting an increase in grain-size. A small area of “rock outcrop facies” is imaged near Muglins where exposed rock generates a strong return signal (Figure 5.5d). Other distinct but localised facies include the “localised backscatter facies” (Figure 5.6a) which reveals an isolated area of high backscatter sediment west of the Burford Bank. This *may* represent a sewage dump. In the “stable seabed facies” localised concentric features are present which were probably caused by boat moorings or possible prop-wash disturbance from large vessels (Figure 5.6b).

Also imaged during the survey are two shipwrecks. The two shipwrecks are of comparable size with one located on the crest of the Kish Bank (Figure 5.6c & 5.6d). The third target stands proud of the seabed and is probably a rock pinnacle lying east of the Muglins (Figure 5.7a).

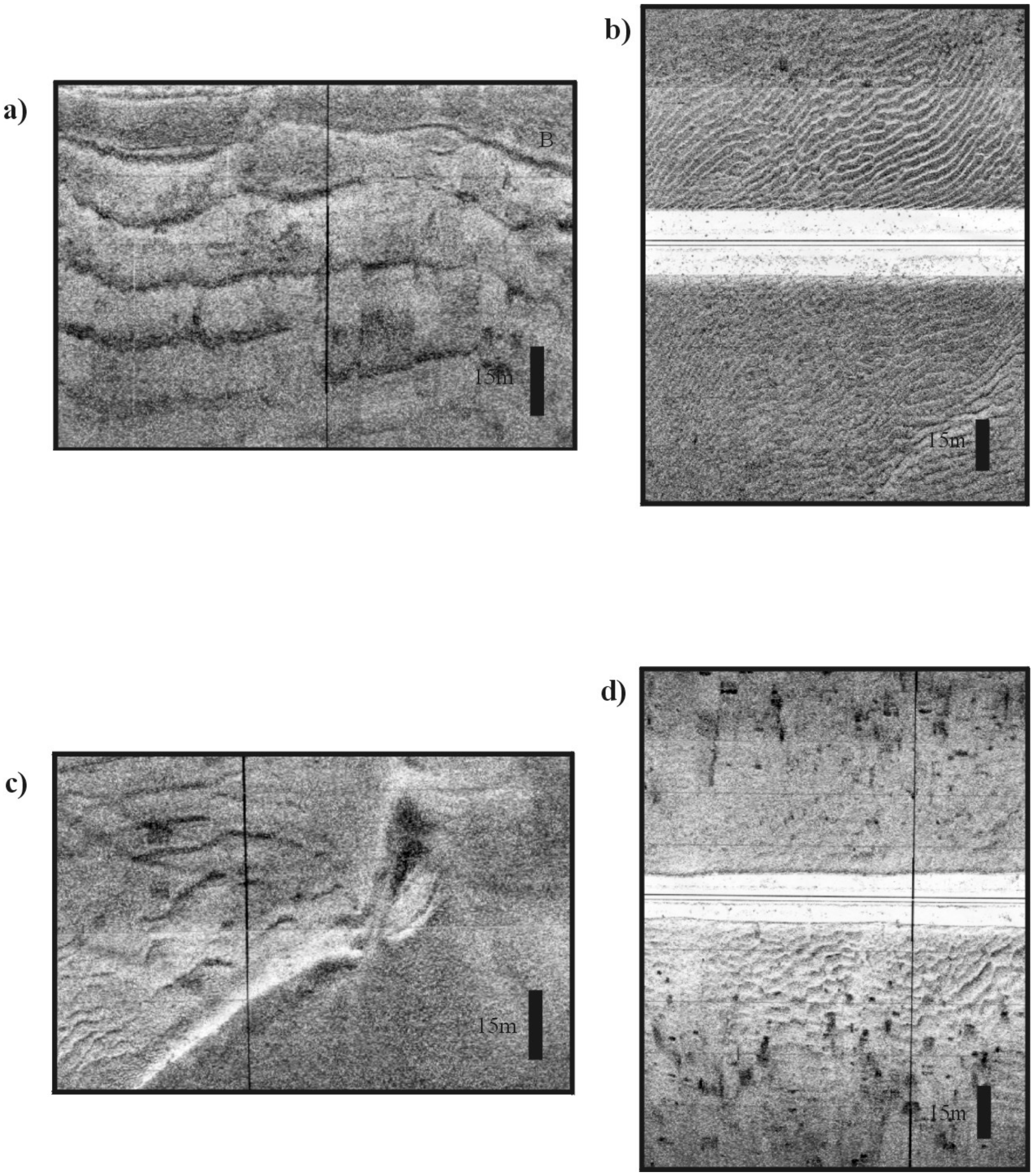

Figure 5.4. Side-scan sonograph showing a) large sandwaves in the"sandwave facies"; b) small sandwaves in the “sandwave facies”; c) sandwaves and a sand ridge in the “sandwave facies”; and d) sandwaves and ?gravel patches on the crest of the Kish Bank on the edge of the “stippled bank crest facies”.

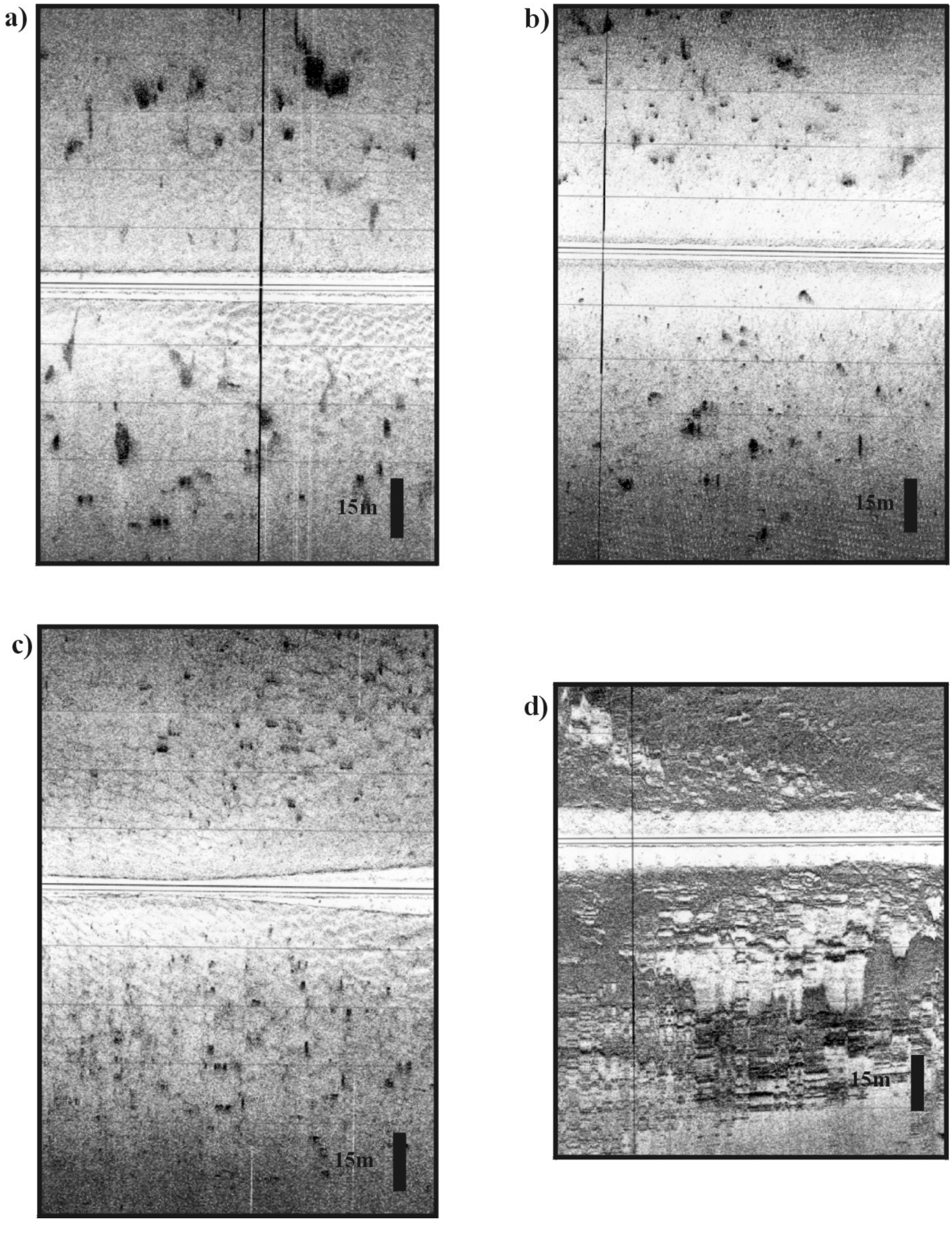

Figure 5.5. Examples of sonographs showing a) small sandwaves and ?gravel patches on the crest of the Kish Bank in the "stippled bank crest facies"; b) planar beds with ?gravel patches on the Kish Bank in the "stippled bank crest facies"; c) small sandwaves and ?gravel patches on the crest of the Kish Bank in the "stippled bank crest facies"; and d) the "rock outcrop facies" from Muglins showing high backscatter returns and acoustic shadows.

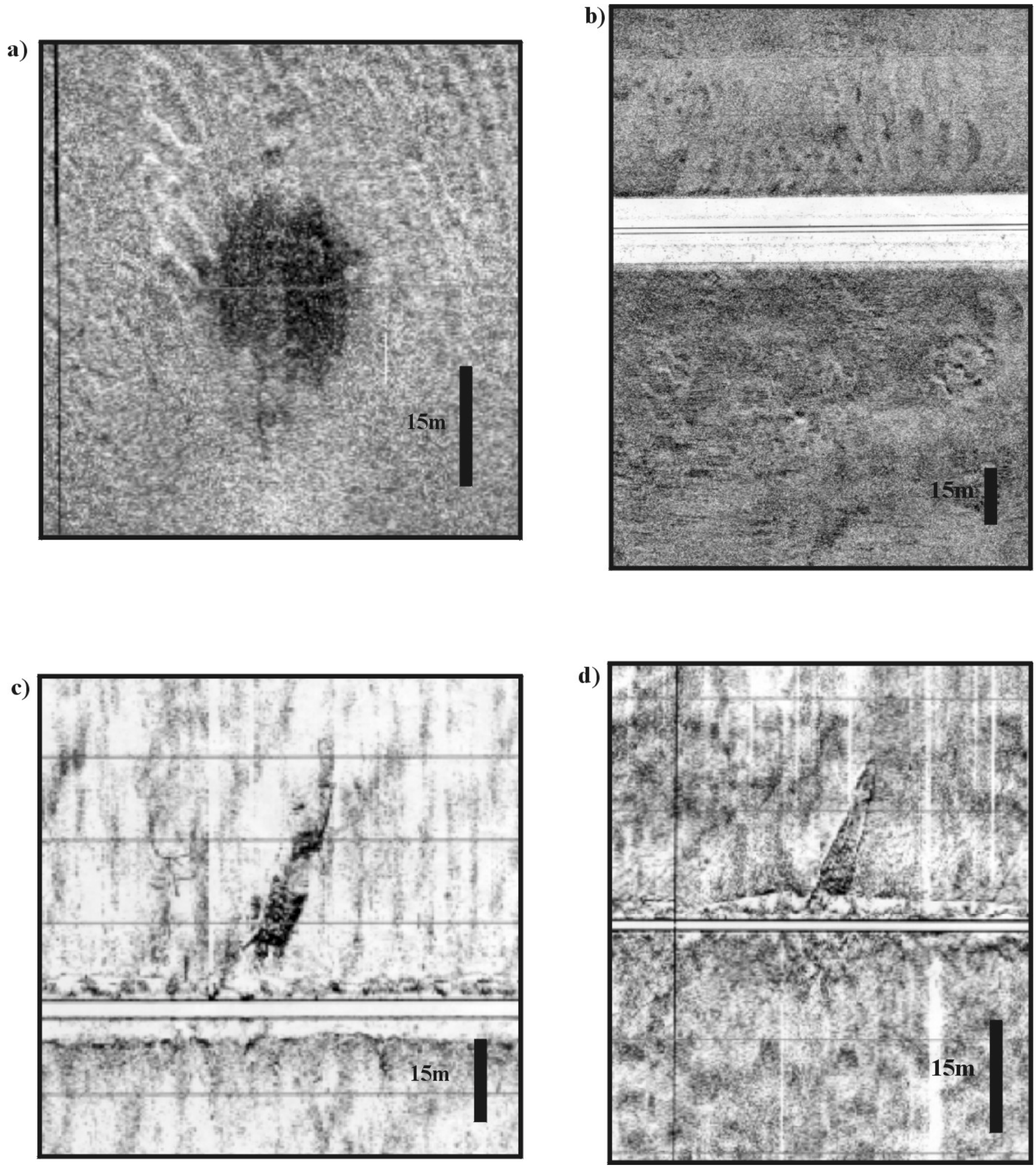

Figure 5.6. Examples of sonographs showing a) the "localised backscatter facies" revealing an isolated patch of high reflective sediment overlying sandy sediment with sandwaves; b) disturbance of the seabed in the "stable seabed facies" probably caused by vessel activity; c) & d) shipwrecks imaged on the crest of the Kish Bank.

6. Seismostratigraphy

Seismic sediment profiling provides seismostratigraphic correlation with adjoining stratigraphies and allows an assessment of temporal processes. Due to operational difficulties, the internal stratigraphies of offshore banks on the east coast of Ireland are poorly understood. This study therefore provides valuable insights. The coverage of boomer seismic lines is presented in Figure 5.1 coincident with the centre of side-scan sonar swathes. Profiling was performed across all banks and intervening seabed although less boomer than side-scan coverage was obtained, owing to boomer susceptibility to data loss under poor sea conditions.

A simple seismostratigraphy was revealed comprising an upper layer of sand with weak internal reflectors (Unit A) suggesting that density contrasts within the unit are minimal. This unit overlies a thin unit with a strong response (Unit B) that is present at a comparable altitude throughout the survey area. Below Unit B are poorly imaged strata with few internal reflectors (Unit C) which occasionally contain other thin beds comparable with Unit B although spatially discontinuous. Unit A and Unit B are correlated with Unit IV of Whittington (1977): banks and other sand bodies that may include stiff clay or gravel layers and mud and silt in some hollows. Furthermore, Unit B can be correlated with Reflector A (Irish Shell Petroleum Development Company, 1979) which is a “stiff clay”. The planar nature of the unit suggests that it *may* represent early Holocene low energy marine facies. The underlying and overlying sands and silts probably represent interglacial marine deposits.

A typical seismic profile is presented in Figure 5.7b between the Burford and Kish Banks. The seabed in this profile shows sandwaves with characteristic crossbedding expressed as internal reflectors in Unit A. Large amplitude sandwaves are apparent in Figure 5.7c.

Figures 5.7d, 6.1a and 6.1b show seismic profiles from across the Kish Bank and reveal that Unit B retains a consistent altitude as the seabed rises over the Bank (Figure 5.7d & 6.1a). The banks contain no additional internal reflectors (Figure 6.1b) suggesting that both the Kish, Burford, Bray and Fraser Banks are composed of sand/gravel with no density contrasts and are not founded on a glacial morainic core as in the case of the Arklow Bank (R. Keary, *pers. comm*.).

Other features apparent on the boomer profiles include the presence of a buried erosion feature (Figure 6.1c). Figure 6.1d shows chaotic return signals generated by rock outcrops at the seabed near Muglins.

Isopachs for Unit A (measured from the seabed to the upper surface of Unit B) are presented in Figure 6.2. The thickest accumulations occur over the Kish (38m), Bray (37m) and Burford Banks. It should be noted that the irregular nature of the isopach map in the vicinity of the banks is due to a paucity of data. Unit B has an average thickness of *c*. 20m between the banks and thins towards Dublin Bay.

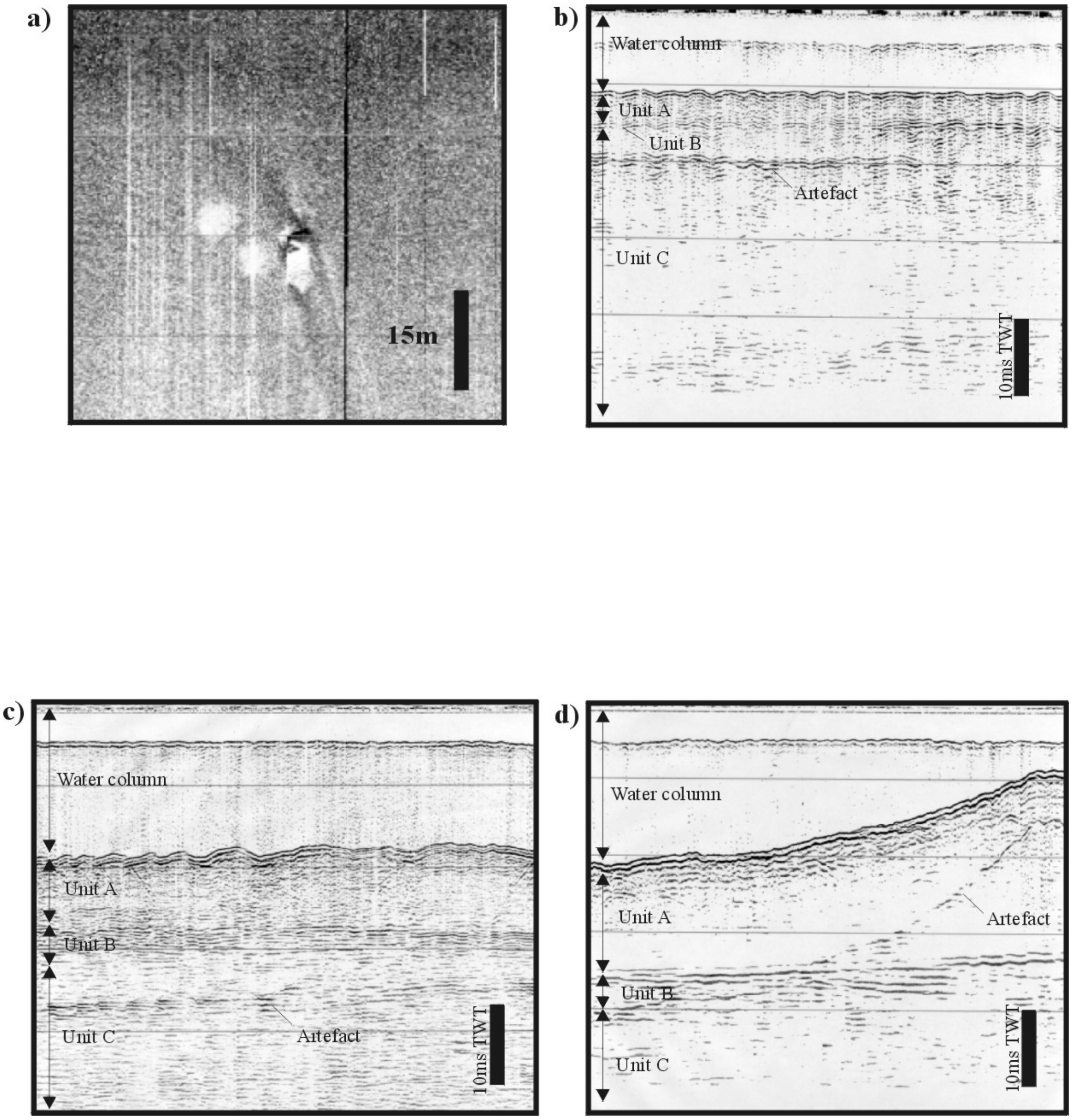

Figure 5.7. a) Side-scan sonograph of a probable rock outcrop imaged near Muglins; b) typical boomer profile through the seabed between the Kish and Burford Banks; c) boomer profile through a field of high amplitude sandwaves; and d) boomer profile through the western edge of the Kish Bank.

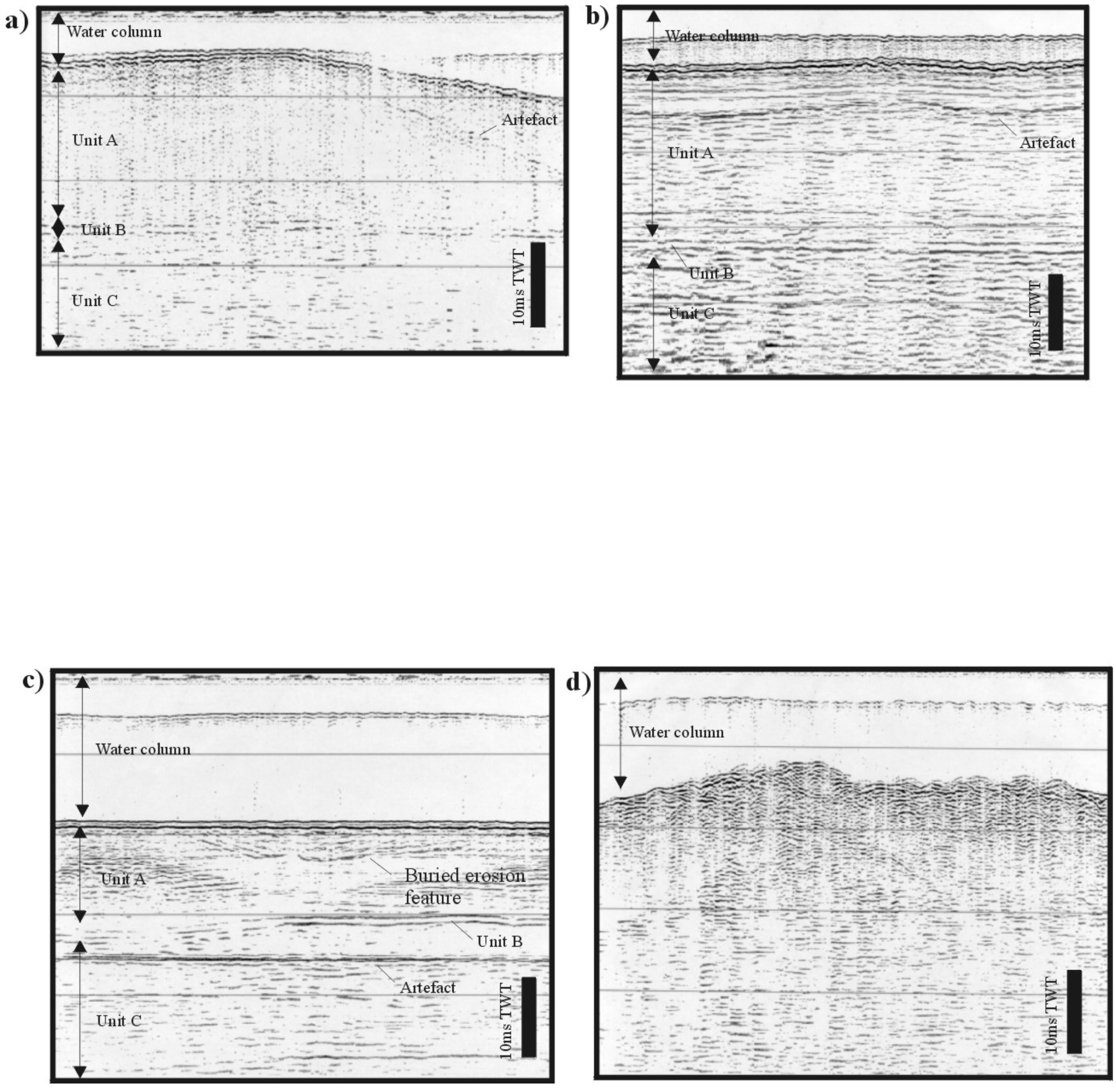

Figure 6.1. Boomer seismic profiles a) through the eastern edge of the Kish Bank; b) through the crest of the Kish Bank; c) showing a buried erosion feature; and d) over rocks outcropping on the seabed near the Muglins.

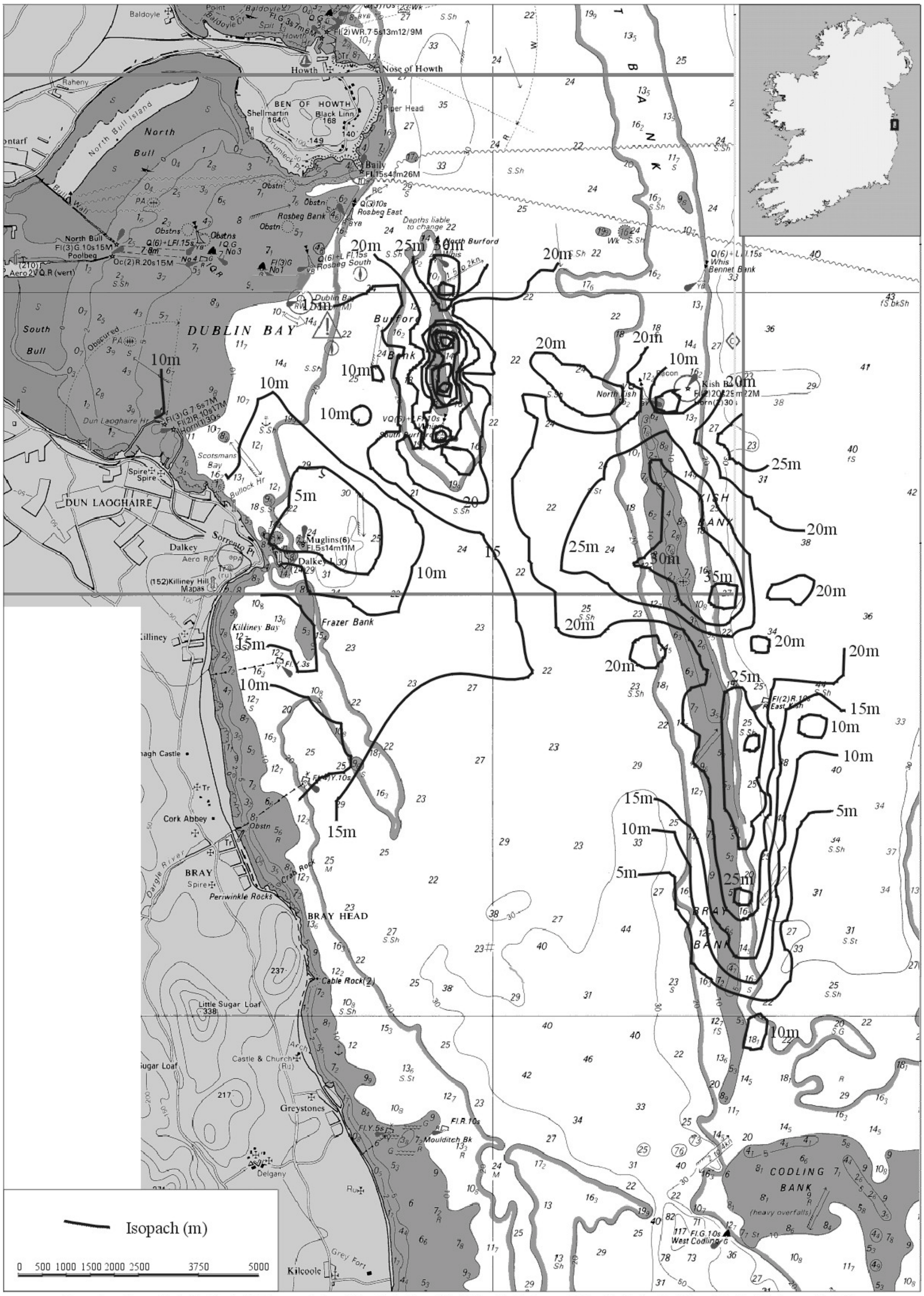

Figure 6.2. Isopach map showing the thickness of Unit A, the uppermost stratigraphic unit. Isopach fixes and selected readings are also presented.

7. Sediment properties

As well as providing essential ground-truthing to the geophysical data, the sediment properties in themselves provided important information with respect to geological processes. The location of sediment samples taken during the survey is presented in Figure 7.1. Samples were subjected to particle size analysis (see Appendix I for conversion between phi and millimetres) that classified most of the sediments as "medium sand" with a mean particle-size of 2 phi (0.25mm) to 1 phi (0.5mm) (Figure 7.2 & Appendix II). Examples of particle size distributions are presented in Figure 7.3 showing the degree of variation present in the dataset. Three dominant particle size modes are revealed whose variable representation dictates overall sediment type: a gravel mode (<-3 phi or <8mm), a sand mode (centred on 1 phi or 0.5 mm) and a silt mode (centred on 6.5 phi or 0.012mm). Samples were ascribed to sediment types based on the Folk (1954) classification scheme (Figure 7.4).

Defined sediment types are plotted spatially in Figure 7.5 and show a dominance of sandy sediment both on the banks and in the intervening areas. Gravelly sediments are concentrated on the bank crests (i.e. the Kish Bank and especially the southerly Bray Bank) and silty sediments are restricted to deeper waters away from the banks. It should be noted that when the Van Essen Grab is used, large clasts may get caught in the jaws of the grab and cause fine sediments to be undersampled. This may result in an apparent exaggeration of the degree to which samples coarsen on bank crests and towards the south. However, a coarsening of sediments to the south (and increase in sediment lag) is still implied - which is also supportive of a northerly net sediment transport direction as implied by imaged bedforms.

Percentage carbonate determinations were also performed on the sediments (Figure 7.6) and reveal a variation of between 0% and 15% with most samples containing between 1% and 5% carbonate. Zero carbonate samples were obtained from lithic-gravel samples (probably under-represented in fines) whereas those samples with high carbonate value also represent coarse-grained sediments with a detrital shell component. No clear relationship exists between carbonate content and grain-size.

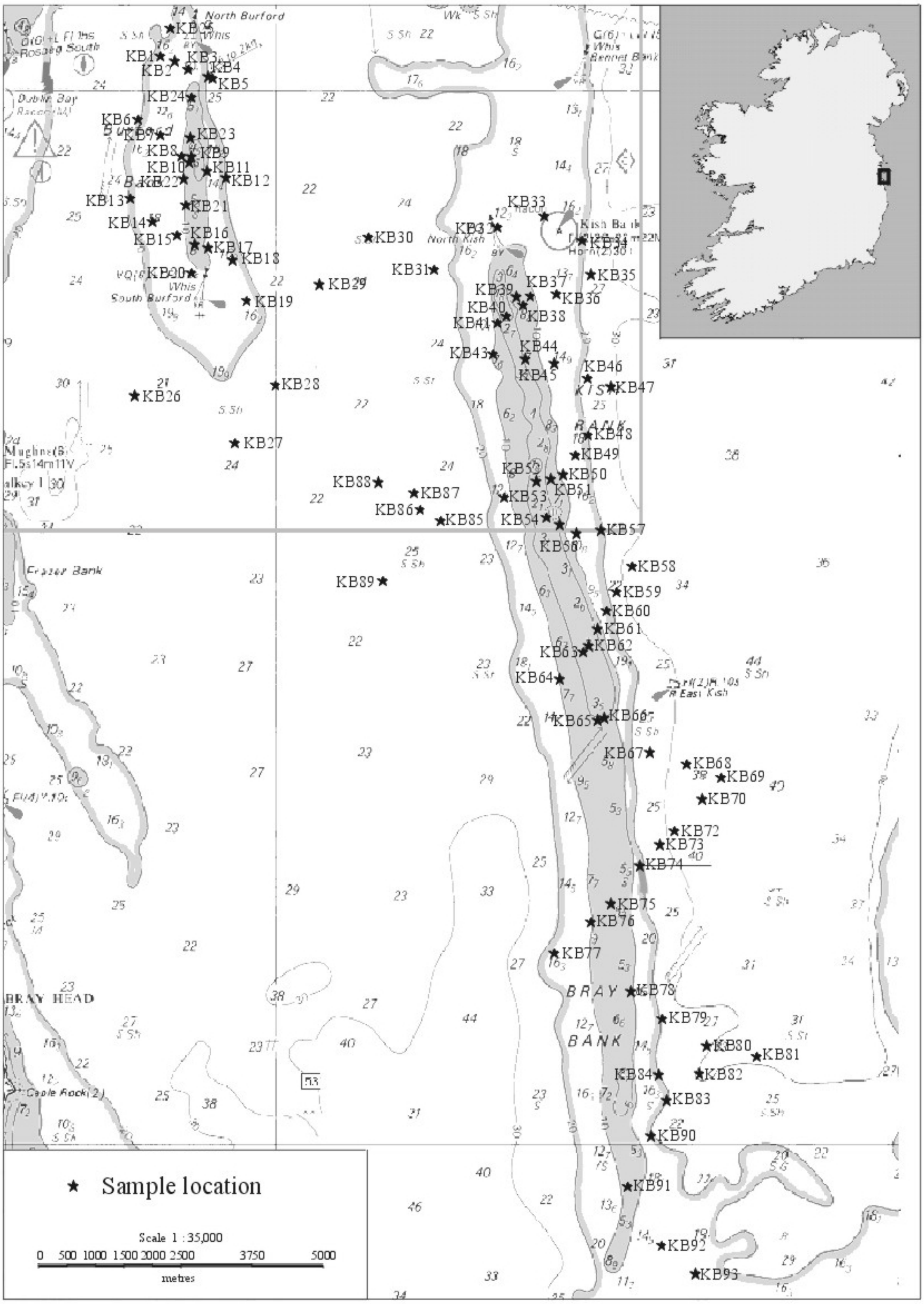

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Figure 7.1. Location of sediment samples.

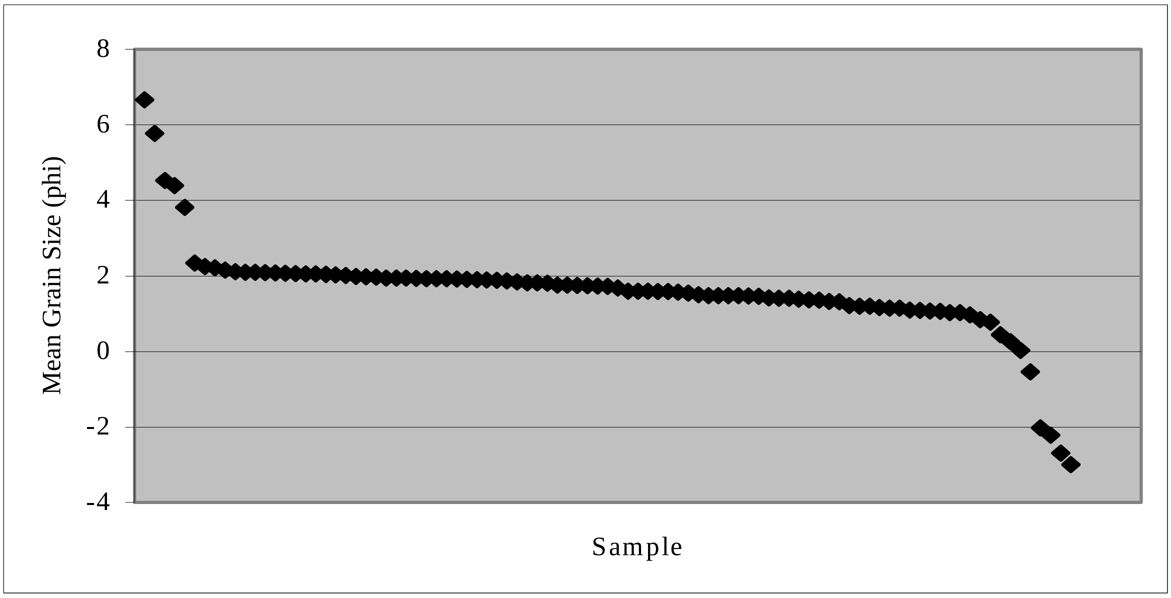

Figure 7.2. Variation in mean particle size.

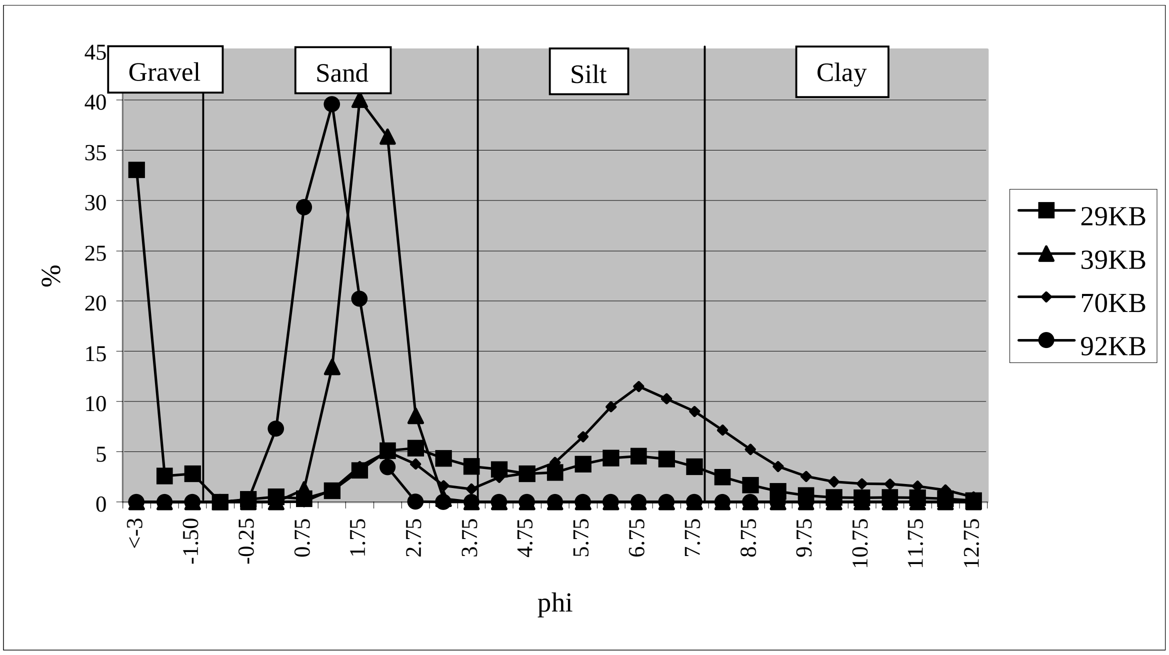

Figure 7.3. Representative particle-size distributions.

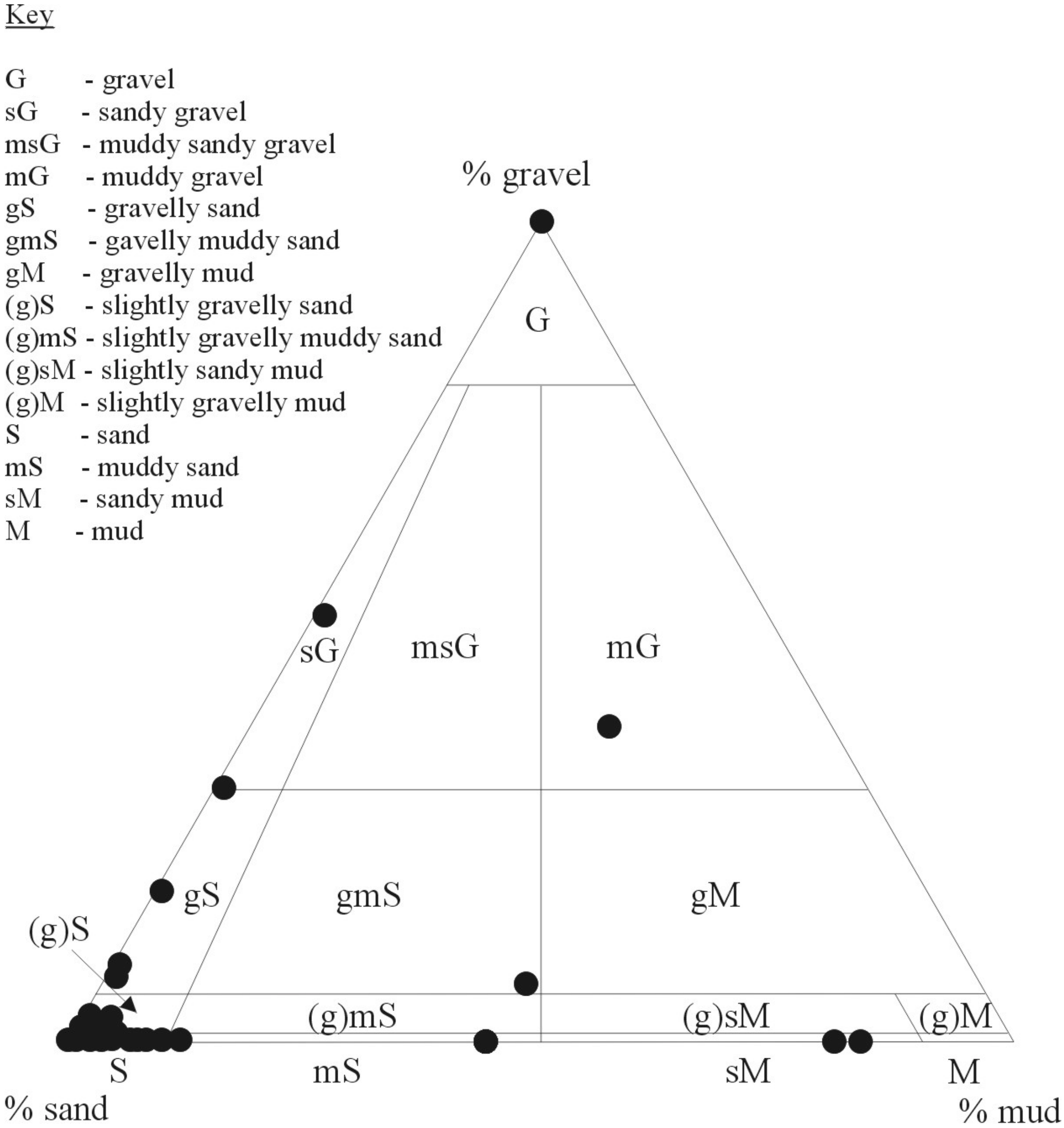

Figure 7.4. Sediment type classification based on percentage sand, mud and gravel (after Folk 1954).

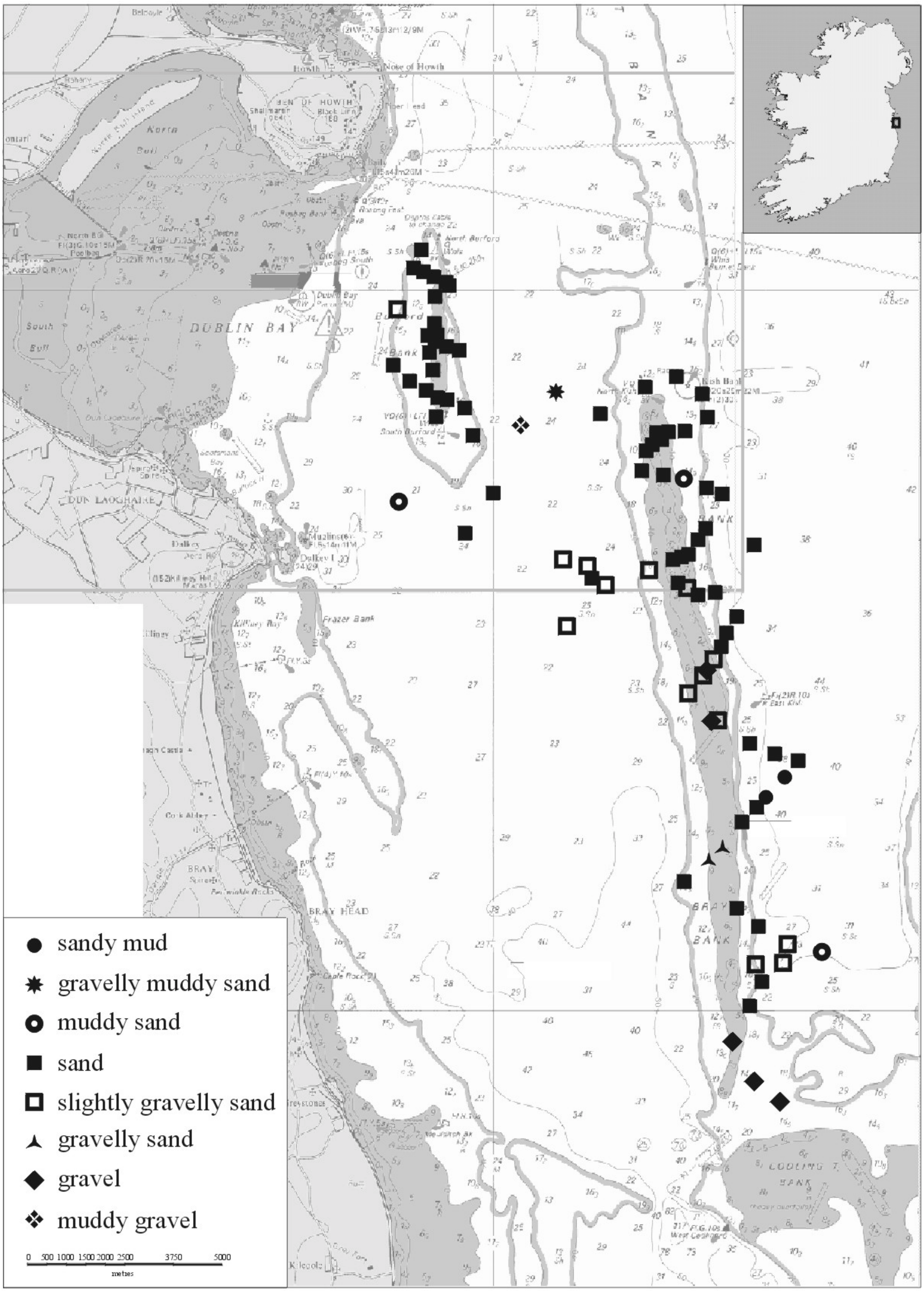

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Figure 7.5. Spatial distribution of derived sediment types.

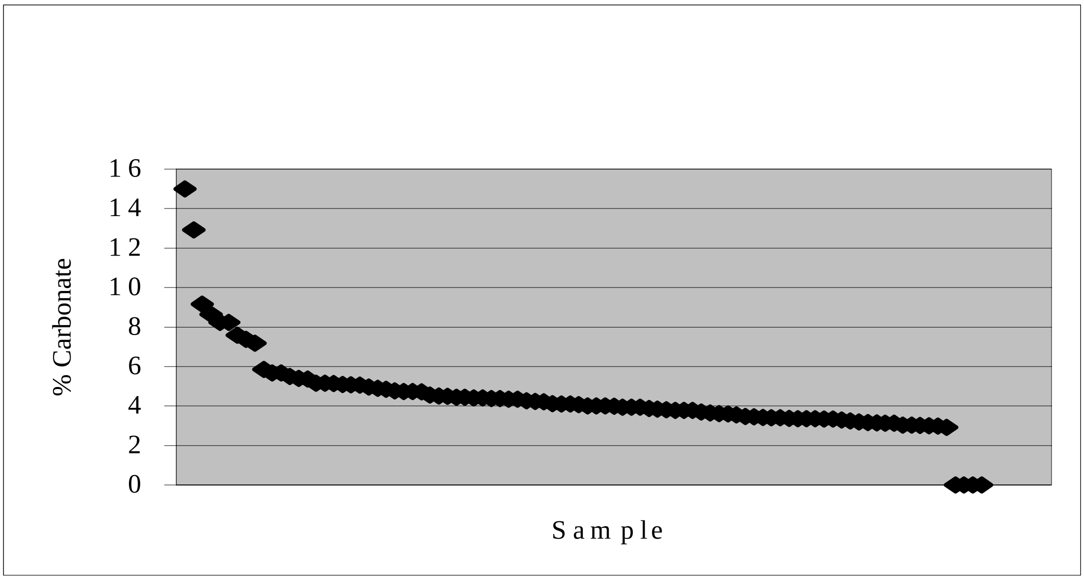

Figure 7.6. Variation percentage carbonate.

8. Conclusions

The results outlined above detail, in three dimensions, the geological attributes of an area of offshore banks and intervening seabed east of Dublin. It is not possible to say if the Banks have changed their position over the last 100 years although substantial migrations cannot be discerned. Changes in bank heights are apparent to the extent that the existing charts are unreliable for across-bank navigation. Although shipwreck incidence on the banks is high only two shipwrecks were imaged suggesting a low preservation potential for maritime heritage.

Side-scan sonar records reveal evidence of seabed mobility on, and adjacent to, the banks. Furthermore, sandwaves increase in amplitude towards the edge of the banks suggesting that currents are highest close to the banks. This is probably responsible for the maintenance of the banks' relative positions. Away from the banks, the seabed is less affected by current activity and finer-grained seabed with small or no bedforms is encountered. On, and adjacent to, the banks small patches of probable gravel were imaged. Given the high incidence of shipwrecks in the area, these lag deposits may also contain components of shipwreck debris.

The seismic data revealed the upper mobile sands (Unit A) attaining considerable thicknesses and resting on a planar strong reflector (Unit B). Bank formation occurred after the deposition of Unit B with banks composed of poorly stratified sand/gravel. Unit A and Unit B are correlated within Unit IV of Whittington (1977). Unit B is further correlated with Reflector A (Irish Shell Petroleum Development Company, 1979) which is a "stiff clay". The planar nature of the unit suggests that it *may* represent early Holocene low energy marine facies. The underlying and overlying sands and silts probably represent Holocene or interglacial marine deposits.

Grain-size variations show a tendency for coarser grain-sizes to be dominant on the southern Bray Bank and fining northwards and away from the banks. This is in agreement with sandwave orientations suggesting a northerly sediment transport direction.

9. Acknowledgements

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A bibliography of Irish sand and gravel resources containing 406 bibliographic entries is included in the Sand & Gravel Database (Appendix III; for further information contact (a) the authors at the Coastal Resources Centre, University College Cork, Presentation Buildings, Western Rd., Cork, Ireland. g.sutton@ucc.ie; a.wheeler@ucc.ie or (b) the Marine Data Centre, Marine Institute, 80 Harcourt Street, Dublin 2. data.centre@marine.ie)

APPENDIX I

This appendix presents the relationship between particle-size in phi and mm, such that:

phi = $-\log_2 S$

where,

S = particle size

<table>
<tr><th colspan="5">Sediment Size</th></tr>
<tr><th rowspan="2">Phi</th><th rowspan="2">mm</th><th colspan="3">Class term</th></tr>
<tr><th colspan="2">Wentworth (1922)</th><th>Folk (1954)</th></tr>
<tr><td>-8</td><td>256</td><td colspan="2">boulders</td><td rowspan="8">gravel</td></tr>
<tr><td>-7</td><td>128</td><td colspan="2" rowspan="2">cobbles</td></tr>
<tr><td>-6</td><td>64</td></tr>
<tr><td>-5</td><td>32</td><td colspan="2" rowspan="4">pebbles</td></tr>
<tr><td>-4</td><td>16</td></tr>
<tr><td>-3</td><td>8</td></tr>
<tr><td>-2</td><td>4</td></tr>
<tr><td>-1</td><td>2</td><td colspan="2">granules</td></tr>
<tr><td>0</td><td>1</td><td>very coarse</td><td rowspan="5">sand</td><td rowspan="5">sand</td></tr>
<tr><td>1</td><td>0.5</td><td>coarse</td></tr>
<tr><td>2</td><td>0.25</td><td>medium</td></tr>
<tr><td>3</td><td>0.125</td><td>fine</td></tr>
<tr><td>4</td><td>0.0625</td><td>very fine</td></tr>
<tr><td>5</td><td>0.0312</td><td colspan="2" rowspan="4">silt</td><td rowspan="5">mud</td></tr>
<tr><td>6</td><td>0.0156</td></tr>
<tr><td>7</td><td>0.0078</td></tr>
<tr><td>8</td><td>0.0039</td></tr>
<tr><td><8</td><td><0.0039</td><td colspan="2">clay</td></tr>
</table>

APPENDIX II

This appendix presents an inventory of particle size parameters.

Sample	*% gravel*	*% sand*	*% mud*	*Mean (ϕ)*	*Folk classification*
KB 1	0	100	0	1.59	Sand
KB 2	0	98	2	1.72	Sand
KB 3	0	98	2	1.75	Sand
KB 4	0	97	3	1.92	Sand
KB 5	0	97	3	2.08	Sand
KB 6	1	98	1	1.36	Slightly gravelly sand
KB 7	0	98	2	1.60	Sand
KB 8	0	99	1	2.02	Sand
KB 9	0	98	2	2.05	Sand
KB 10	0	100	0	1.95	Sand
KB 11	0	98	2	1.93	Sand
KB 12	0	96	4	1.94	Sand
KB 13	0	98	2	1.73	Sand
KB 14	3	95	2	1.88	Sand
KB 15	0	100	0	2.06	Sand
KB 16	0	99	1	1.98	Sand
KB 17	0	100	0	1.82	Sand
KB 18	0	100	0	1.59	Sand
KB 19	0	100	0	1.54	Sand
KB 20	0	100	0	1.92	Sand
KB 21	0	97	3	2.10	Sand
KB 22	0	100	0	1.98	Sand
KB 23	0	100	0	1.93	Sand
KB 24	0	100	0	1.67	Sand
KB 25	0	98	2	1.57	Sand
KB 26	0	55	45	4.53	Muddy sand
KB 27	0	97	3	2.16	Sand
KB 28	31	68	1	0.26	Gravel
KB 29	38	24	38	2.09	Muddy gravel
KB 30	7	48	45	3.82	Gravelly muddy sand
KB 31	0	100	0	1.07	Sand
KB 32	0	95	5	1.48	Sand
KB 33	0	98	2	2.08	Sand
KB 34	0	99	1	1.75	Sand
KB 35	0	99	1	1.82	Sand
KB 36	0	98	2	2.05	Sand
KB 37	0	100	0	1.94	Sand
KB 38	0	100	0	1.89	Sand
KB 39	0	100	0	1.94	Sand
KB 40	0	100	0	1.03	Sand
KB 41	0	100	0	1.42	Sand
KB 42	2	98	0	0.84	Slightly gravelly sand

Sample	*% gravel*	*% sand*	*% mud*	*Mean (ϕ)*	*Folk classification*
KB 43	0	100	0	1.31	Sand
KB 44	0	100	0	1.48	Sand
KB 45	0	88	12	0.77	Muddy sand
KB 46	0	99	1	1.38	Sand
KB 47	0	98	2	2.04	Sand
KB 48	0	99	1	2.07	Sand
KB 49	0	100	0	1.50	Sand
KB 50	0	100	0	0.02	Sand
KB 51	0	100	0	1.47	Sand
KB 52	0	99	1	1.60	Sand
KB 53	3	96	1	1.36	Slightly gravelly sand
KB 54	0	99	1	1.41	Sand
KB 55	4	96	0	1.20	Slightly gravelly sand
KB 56	0	100	0	1.46	Sand
KB 57	0	100	0	1.48	Sand
KB 58	0	100	0	1.81	Sand
KB 59	0	100	0	1.21	Sand
KB 60	0	100	0	1.48	Sand
KB 61	2	97	0	1.19	Slightly gravelly sand
KB 62	100	0	0	-2.22	Gravel
KB 63	2	97	0	1.09	Slightly gravelly sand
KB 64	3	94	3	1.74	Slightly gravelly sand
KB 65	9	90	1	1.32	Gravelly sand
KB 66	3	97	0	1.75	Slightly gravelly sand
KB 67	0	99	1	1.90	Sand
KB 68	0	98	2	2.22	Sand
KB 69	0	96	4	2.34	Sand
KB 70	0	17	83	6.66	Sandy mud
KB 72	0	19	81	5.77	Sandy mud
KB 73	0	97	3	2.11	Sand
KB 74	0	100	0	1.97	Sand
KB 75	8	92	1	1.06	Gravelly sand
KB 76	18	81	1	1.10	Gravelly sand
KB 77	52	47	1	-0.54	Sandy gravel
KB 78	0	100	0	2.03	Sand
KB 79	0	100	0	1.91	Sand
KB 80	3	96	1	1.86	Slightly gravelly sand
KB 81	0	56	44	4.40	Muddy sand
KB 82	2	96	2	1.84	Slightly gravelly sand
KB 83	0	100	0	1.59	Sand
KB 84	2	97	0	1.14	Slightly gravelly sand
KB 85	3	96	1	0.44	Slightly gravelly sand
KB 86	0	90	10	2.24	Muddy sand
KB 87	1	99	0	1.02	Slightly gravelly sand
KB 88	1	99	0	0.97	Slightly gravelly sand
KB 89	1	98	1	1.41	Slightly gravelly sand

Sample	*% gravel*	*% sand*	*% mud*	*Mean (ϕ)*	*Folk classification*
KB 90	0	99	1	1.14	Sand
KB 91	100	0	0	-2.02	Gravel
KB 92	0	100	0	1.16	Sand
KB 93	100	0	0	-2.69	Gravel
KB 94	100	0	0	-3.00	Gravel

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APPENDIX III

This appendix outlines details of the Sand & Gravel Database (Sutton & Wheeler, in prep.) that represents the wider focus of the study of which the Kish survey is a component.

The overall study aims to provide a comprehensive national survey, for the island of Ireland, of near-shore sand and gravel resources, to a water-depth of 50m, pertinent to all end-users *e.g.* aggregates industry, fisheries, local authorities, etc.. The project endeavours to collate all known information (digital, documentary, archival and other sources) regarding the location and extent of the resources, to deliver this data as a national resource inventory using a GIS-database in line with national standards, and to truth and extend the existing data coverage through additional surveys, where perceived data-gaps or data ambiguities exist pertinent to national needs.

A digital database has therefore been designed to collate, store and visualise a variety of data pertinent to sand and gravel resources. This database comprises three elements;

- a digital data archive,
- metadatabase
- and cross-referenced bibliography.

The database has a GIS component that facilitates fusion, overlay and visualisation of stored geological and environmental data to a common geodetic reference. Cruise tracks, sample locations and sediment type, seabed sediment chart information, biotope information, isopachs, particle size analyses and derived data, borehole and vibrocore logs, seismic and geo-electric profiles, shipwreck locations and bathymetric information are all viewable. The interactive GIS and associated metadata allow rapid sourcing of extant data coverages with comprehensive information of data quality, ownership, survey equipment used, geodetic positional parameters, data descriptions, related datasets, bibliographic links, etc. Multiple coverage overlays can identify data-gaps and data inconsistencies. Detailed seabed information can be instantly accessed on both a site specific and regional scale. The comprehensive metadatabase is compatible with European/IMDC metadata conventions and standards.

This project (Sutton & Wheeler, in prep.) provides a centralised data resource relating to Irish marine sand and gravel deposits pertinent to all end-users. This database highlights our existing knowledge of sand and gravel resources and is expected to be of assistance to marine policy makers as well as resource utilisers. Furthermore, the database is also seen as a potential tool for other offshore geological information end-users and could also act as a platform for further centralised marine information data management exercises.

Further information is available from (a) the authors at the Coastal Resources Centre, University College Cork, Presentation Buildings, Western Rd., Cork, Ireland. g.sutton@ucc.ie; a.wheeler@ucc.ie; or (b) the Marine Data Centre, Marine Institute, 80 Harcourt Street, Dublin 2. data.centre@marine.ie